

# Modeling Light Curves of the Phase-Aligned $\gamma$ -ray Millisecond Pulsar Subclass

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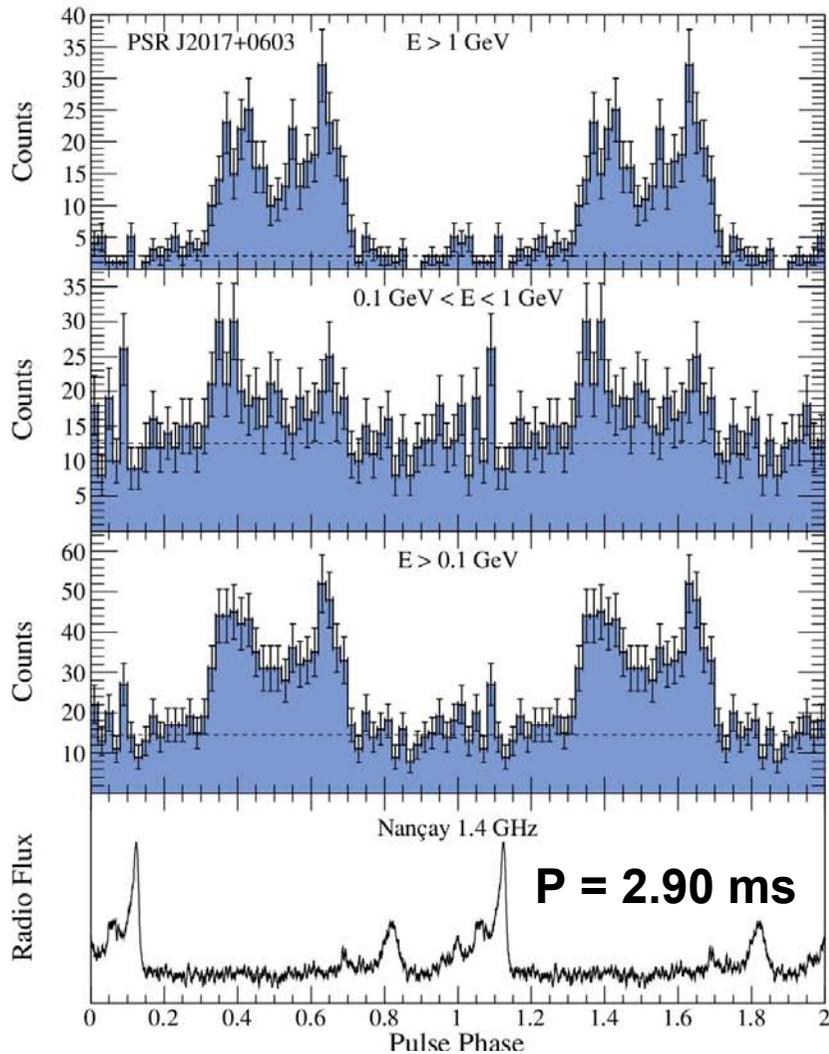
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College Park, MD 20742, USA*

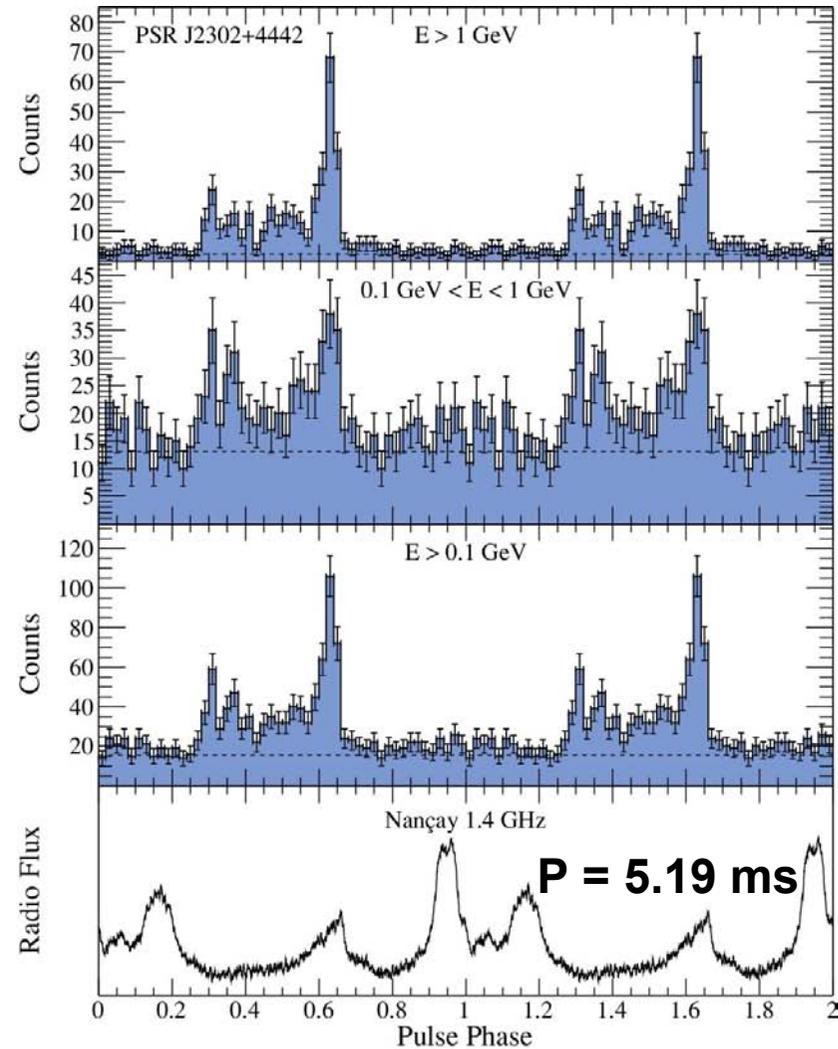
**Fermi Symposium, 9 – 12 May, Rome, Italy**



Cognard et al. (2011)

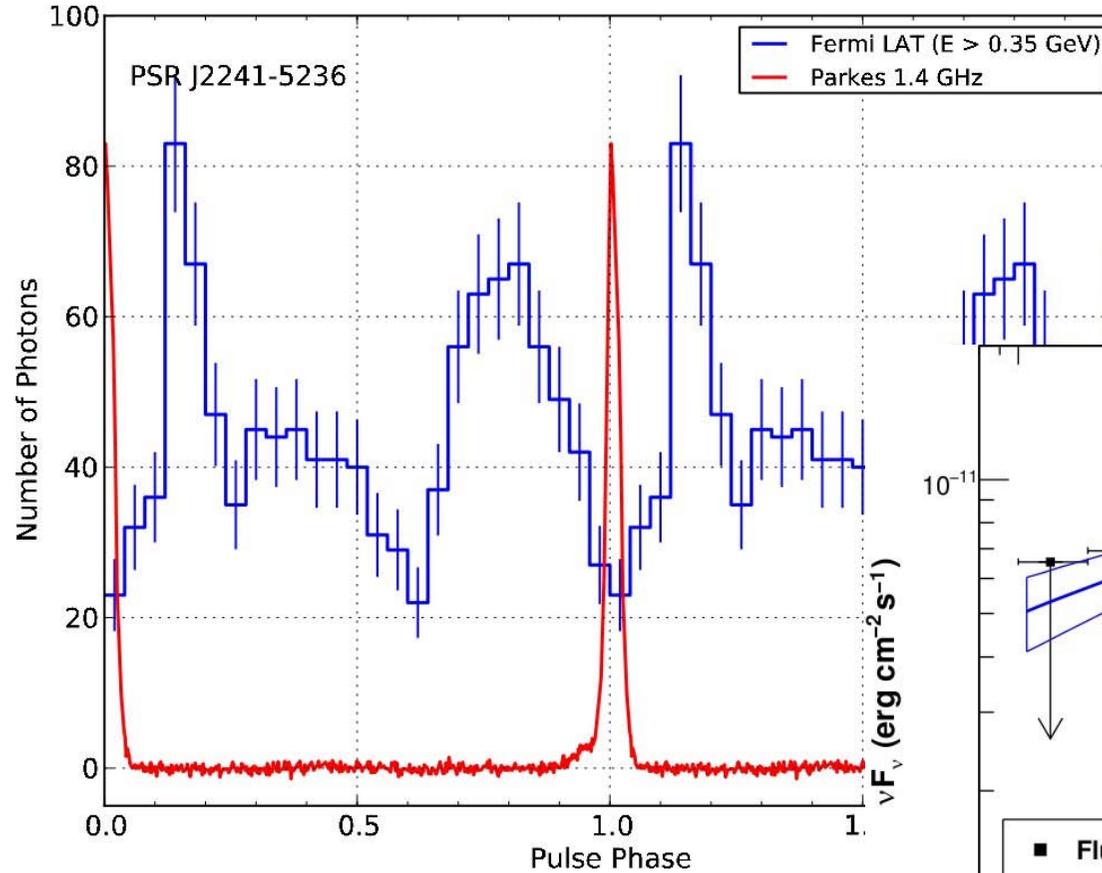


(First 8: Abdo et al. 2009)

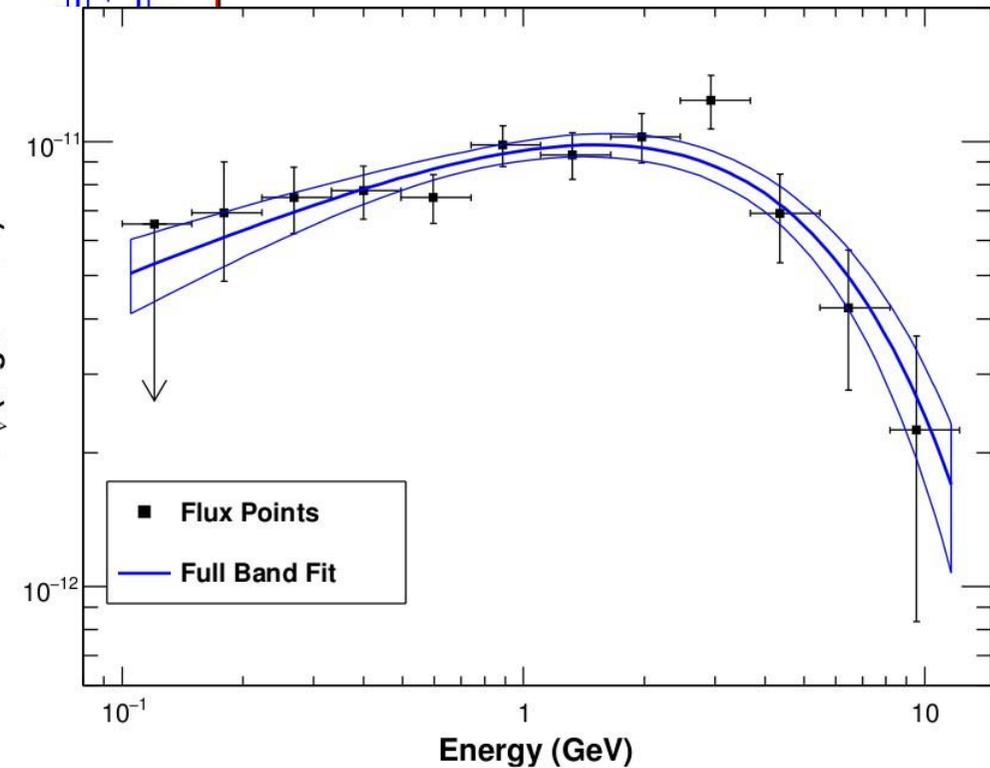


Searches of *Fermi* LAT Unidentified Sources

# And Counting...



Keith et al. (2011)

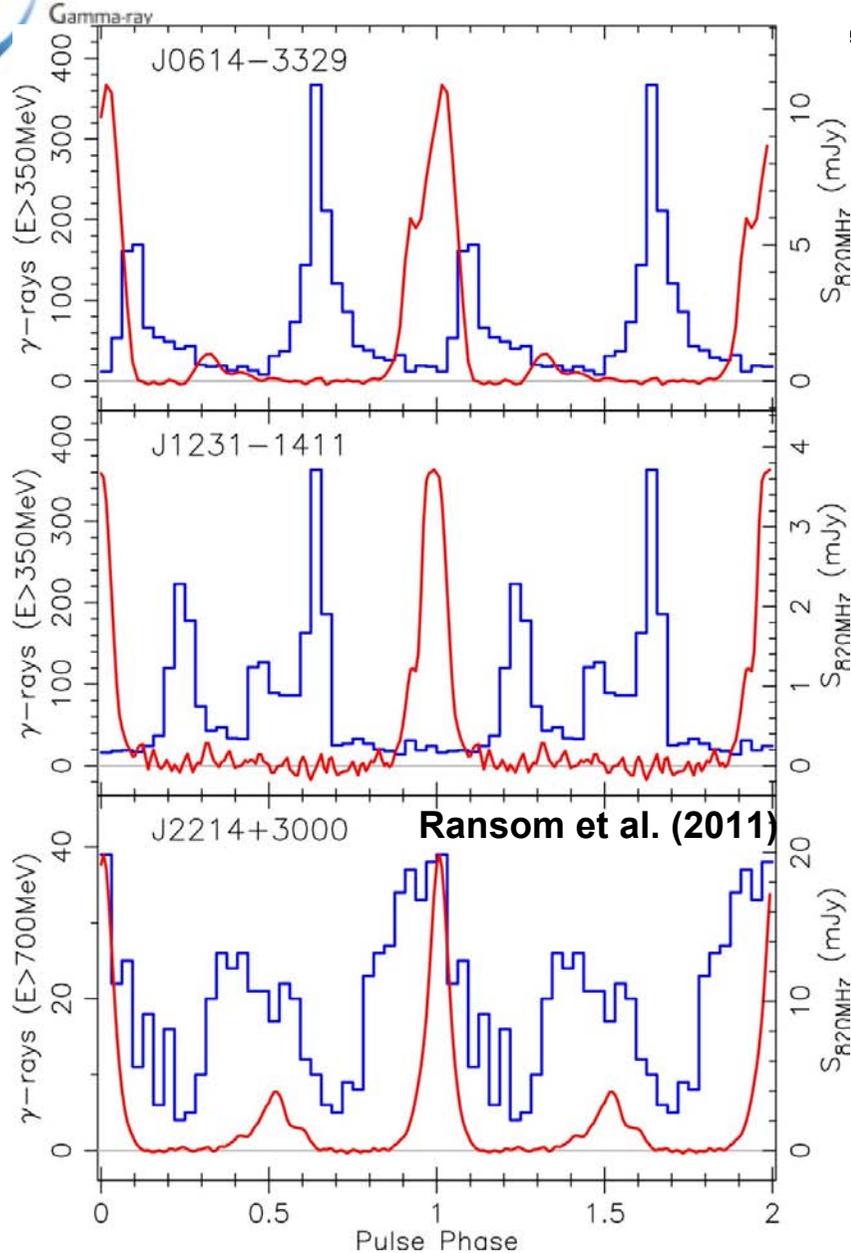


**P = 2.2 ms**  
**Binary system**  
 **$dE/dt \sim 3e34 \text{ erg/s}$**   
 **$d \sim 0.5 \text{ kpc}$**

**Searches of *Fermi* LAT Unidentified Sources**



# And Counting...



**P = 3.14 ms**

**P = 3.68 ms**

**P = 3.12 ms**

**Searches of  
*Fermi* LAT  
Unidentified  
Sources**

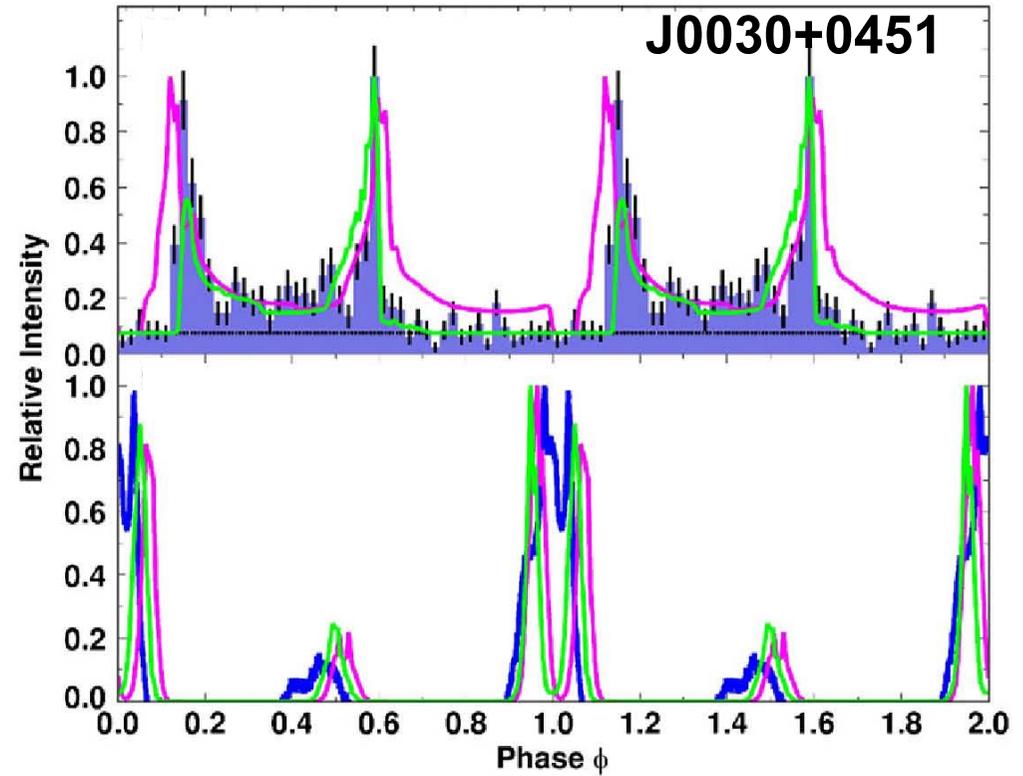
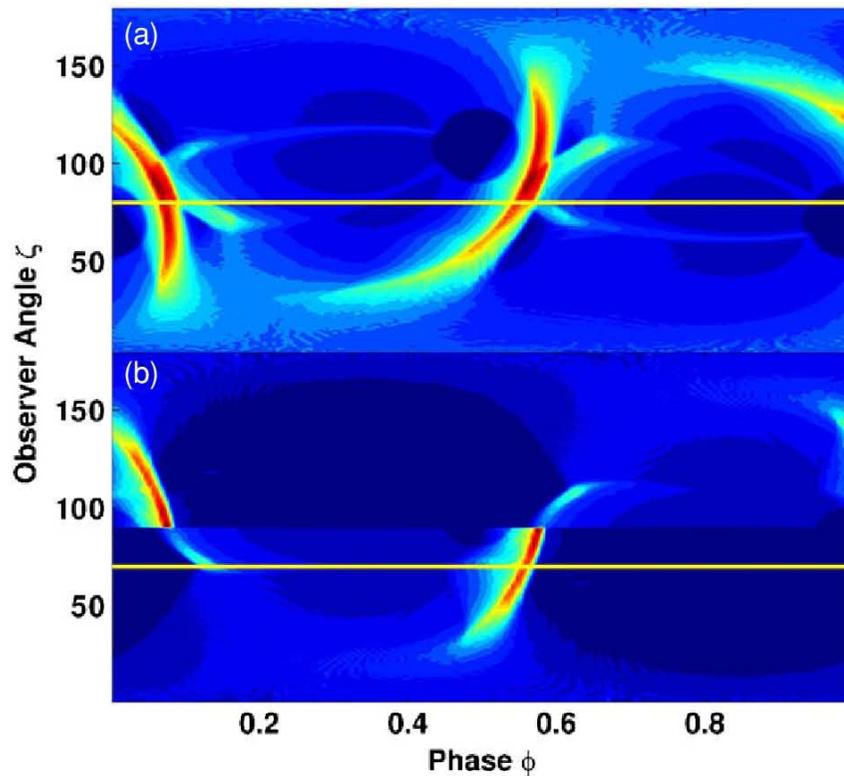
**Now > 20  $\gamma$ -ray MSPs!**

(see talk & poster by R. Romani, & O. Celik)

# Three MSP Subclasses



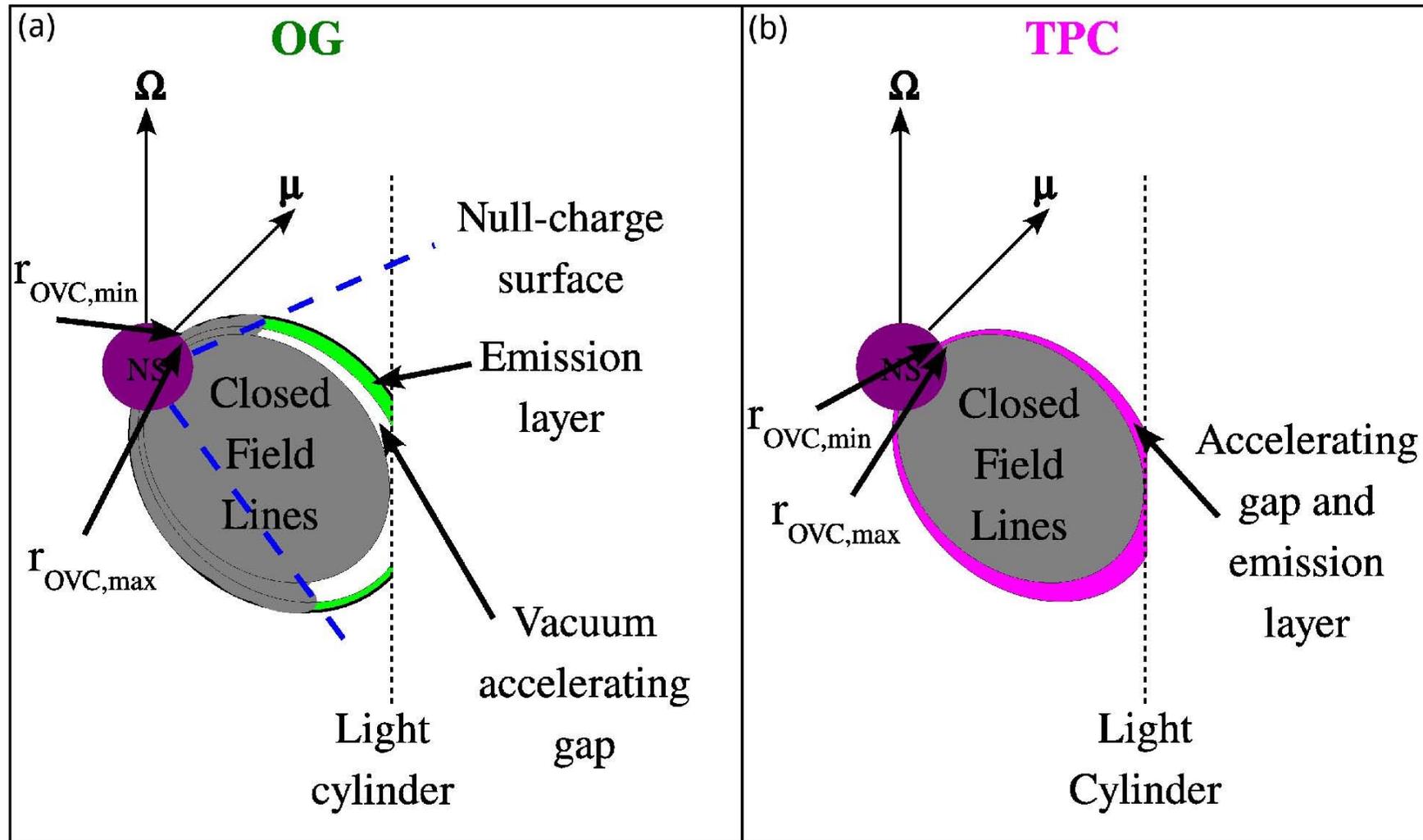
## I. Radio LC preceding $\gamma$ -ray LC



Venter et al. (2009)



## I. Radio LC preceding $\gamma$ -ray LC

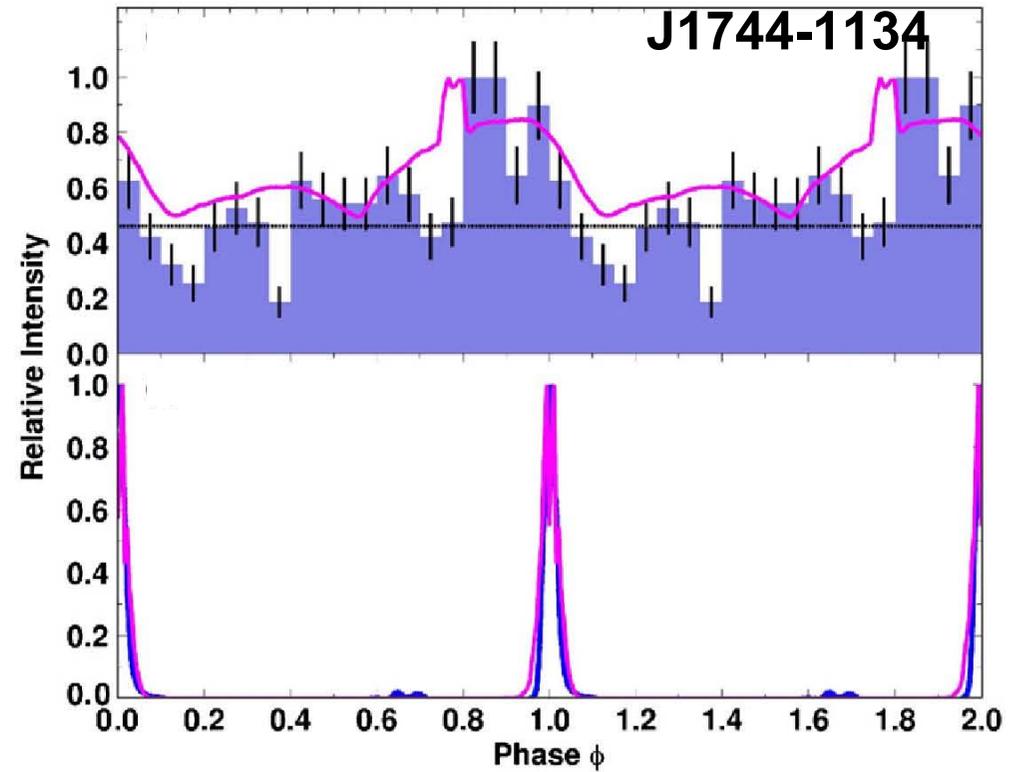
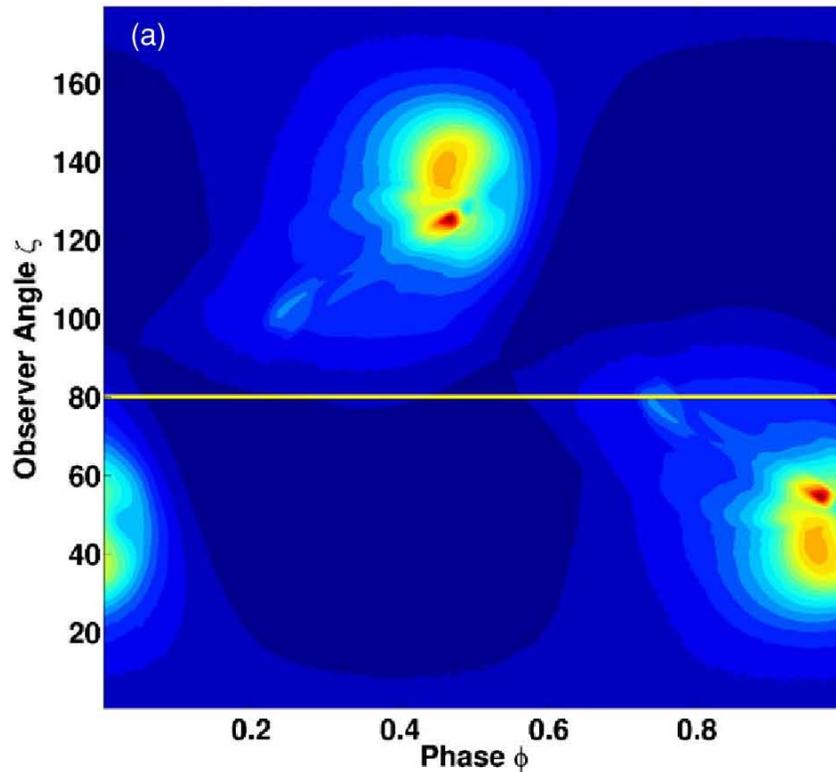


$\gamma$ -ray emission from thin accelerating gaps + conal radio beam

# Three MSP Subclasses



## II. Radio lagging $\gamma$ -ray LC

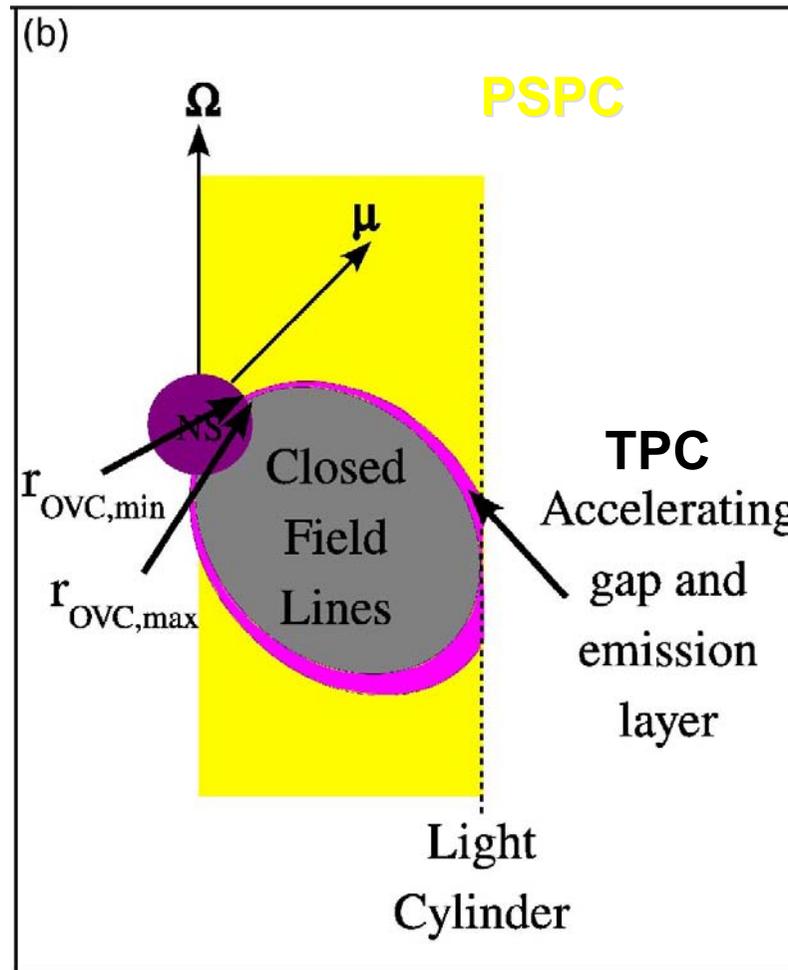


Venter et al. (2009)



### II. Radio lagging $\gamma$ -ray LC

$\gamma$ -ray  
emission  
from full  
open field  
line region;  
conal radio  
beam

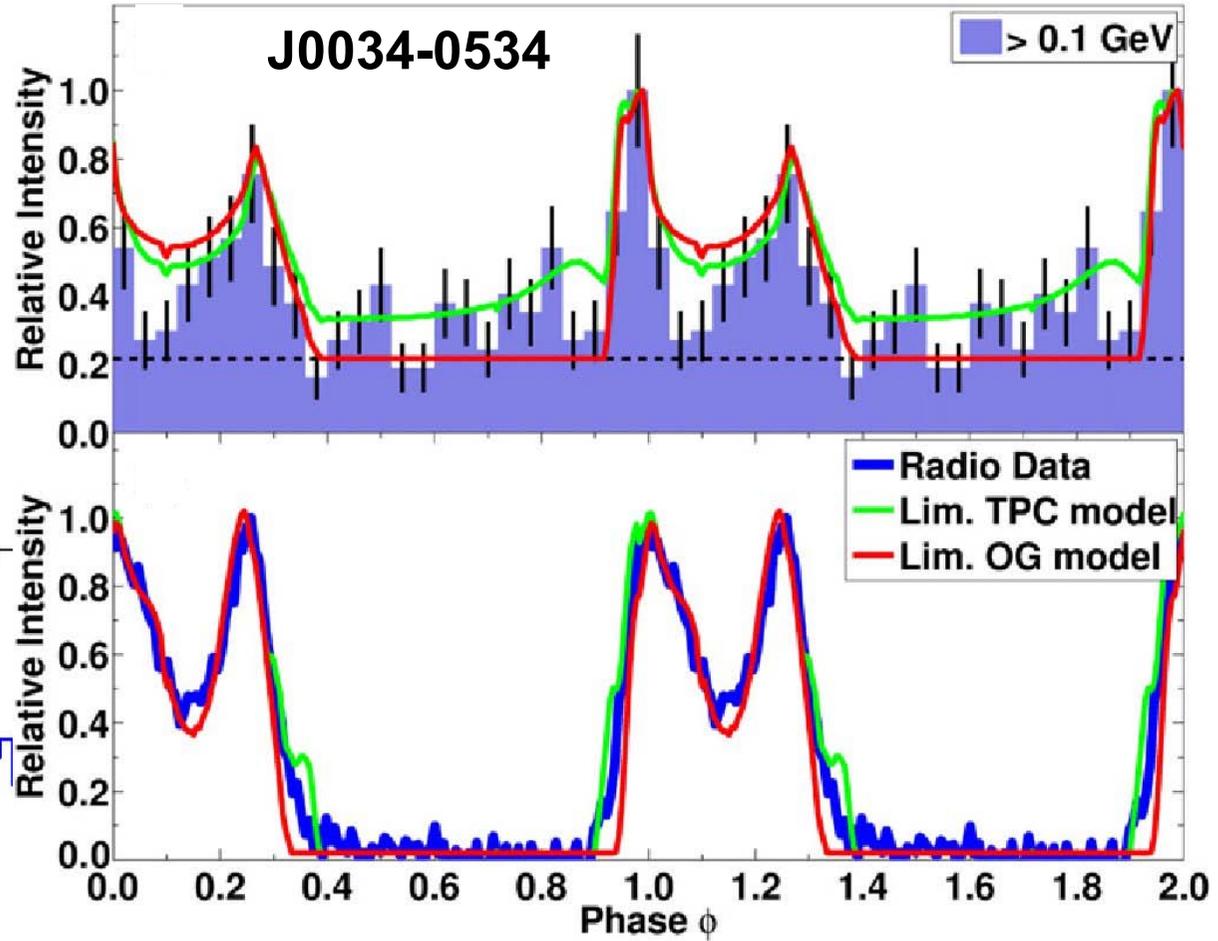


Muslimov & Harding (2004); Venter et al. (2009)

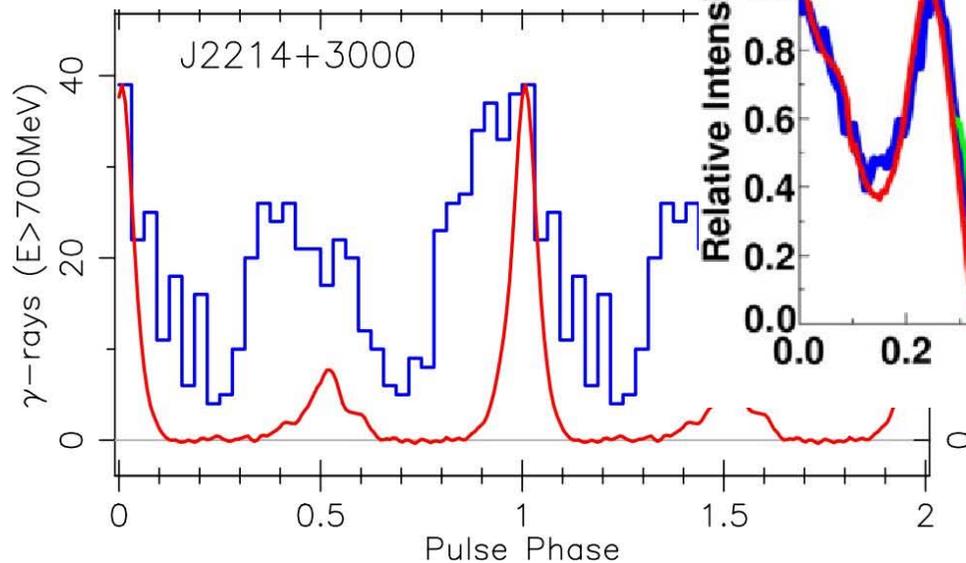
# Three MSP Subclasses



## III. Radio and $\gamma$ -ray LCs in phase



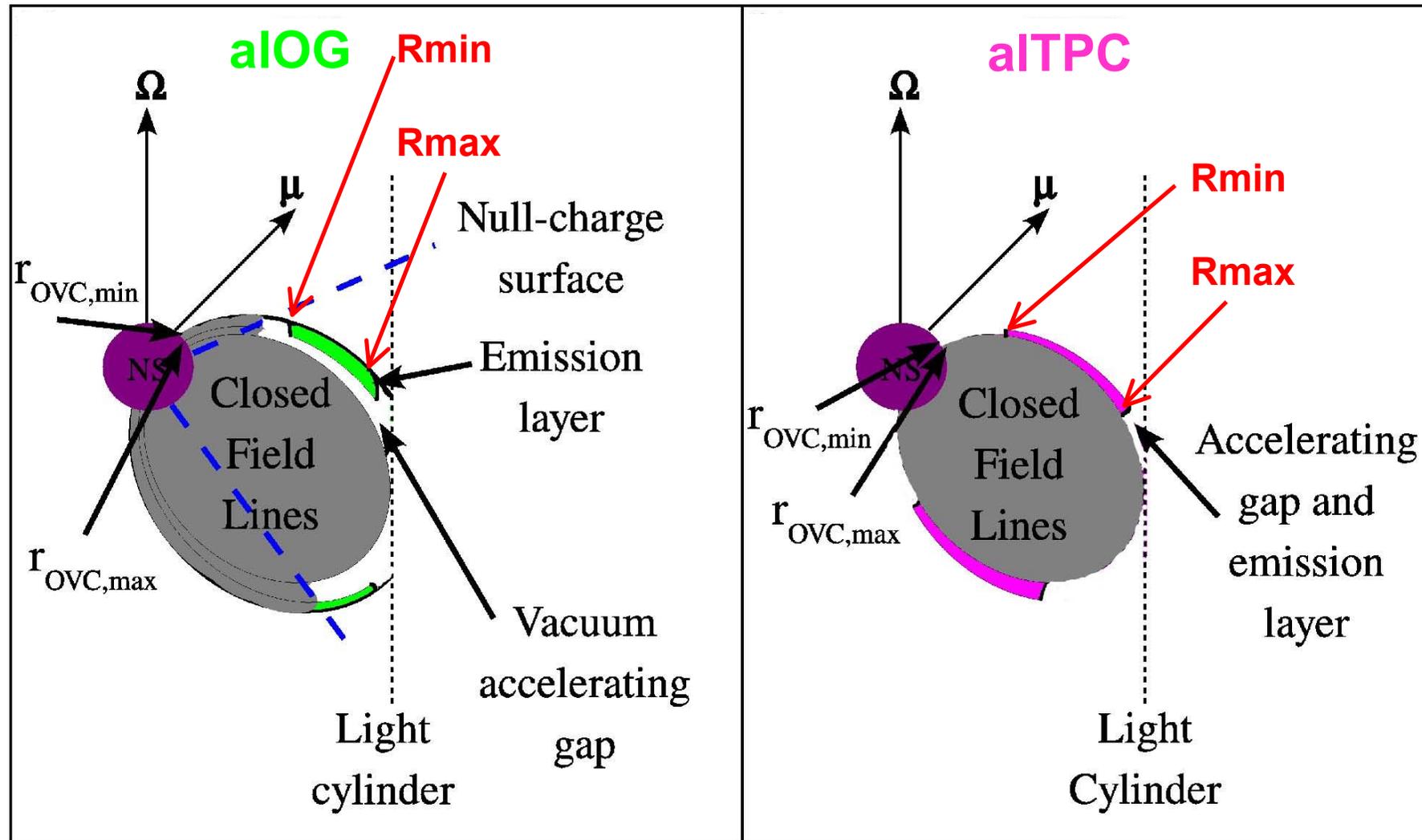
Ransom et al. (2011)



Abdo et al. (2010)



## III. Radio and $\gamma$ -ray LCs in phase



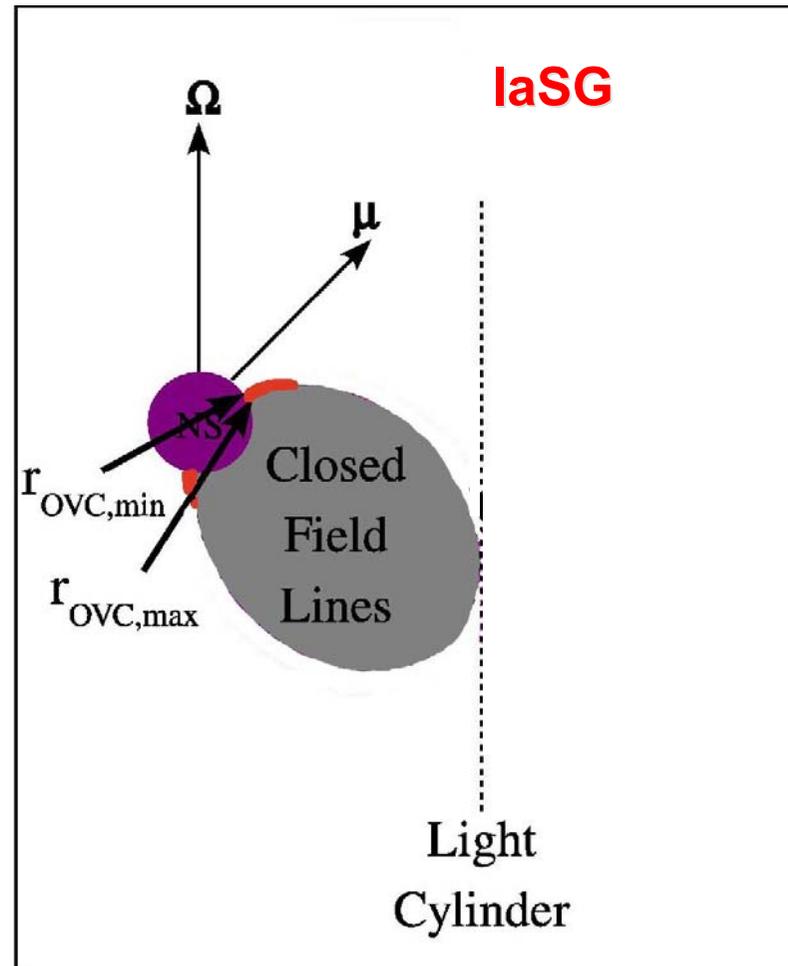
Caustic  $\gamma$ -ray and radio emission from altitude-limited acceleration gaps

## IIIb. Low-altitude Slot Gap



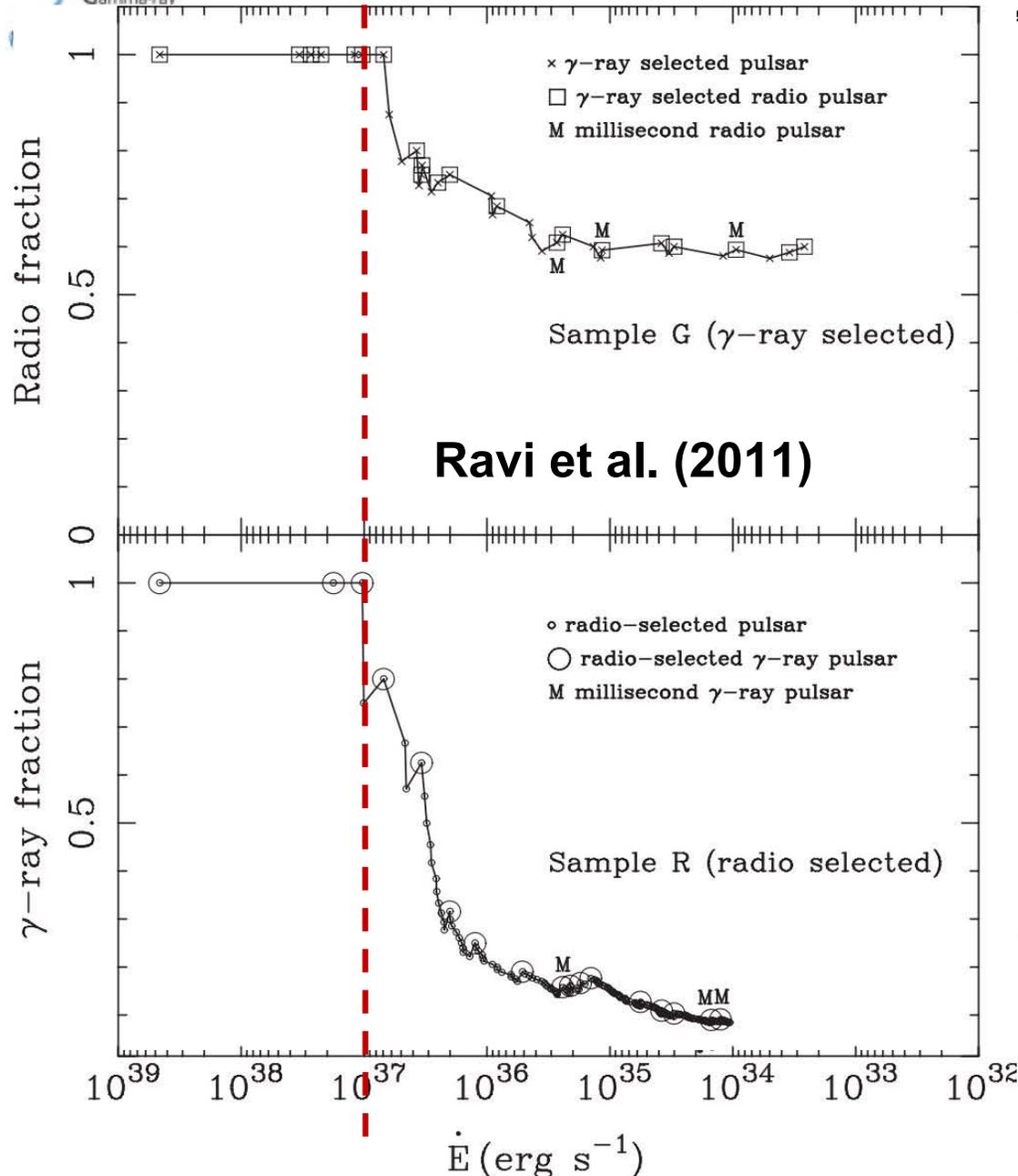
### III. Radio and $\gamma$ -ray LCs in phase

Emission at  
low altitudes  
from annular  
region near  
PC



Venter et al. (2011)

# High-Altitude Caustic Radio Emission



- $\gamma$ -selected and radio-selected pulsars

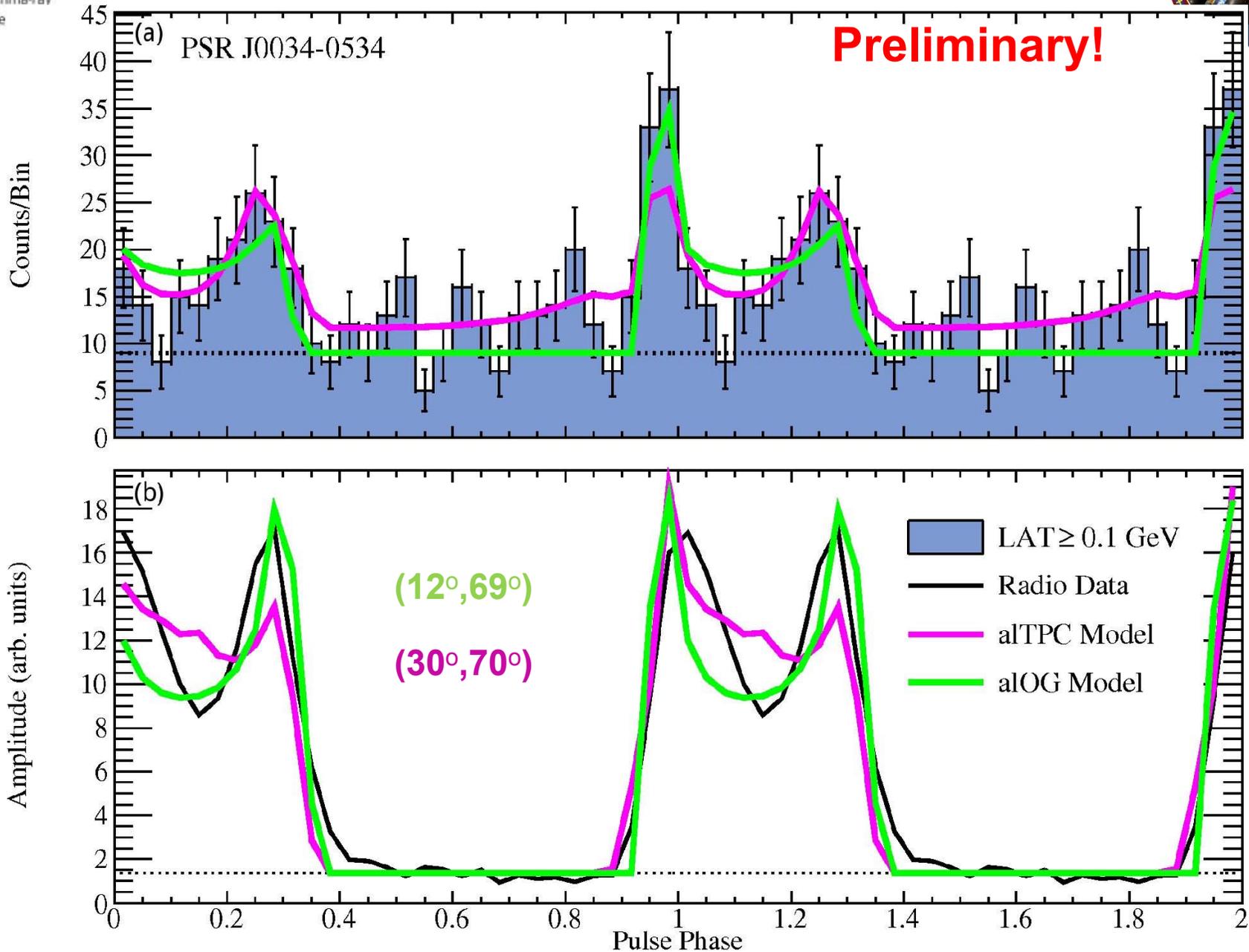
- Comparable sky coverage of  $\gamma$ -ray and radio beams for  $dE/dt > 1e37 \text{ erg/s}$ , since both radio and  $\gamma$ -rays are visible

- **Implication 1:** wide, high-altitude radio beams

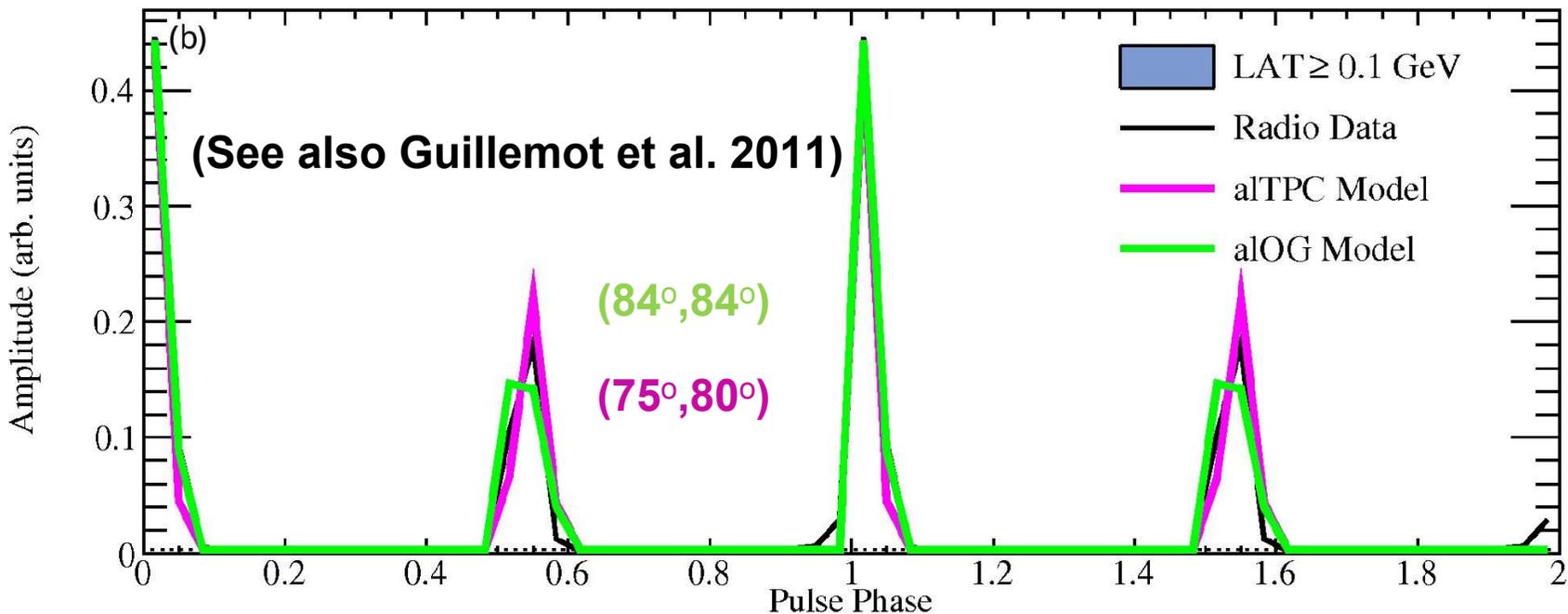
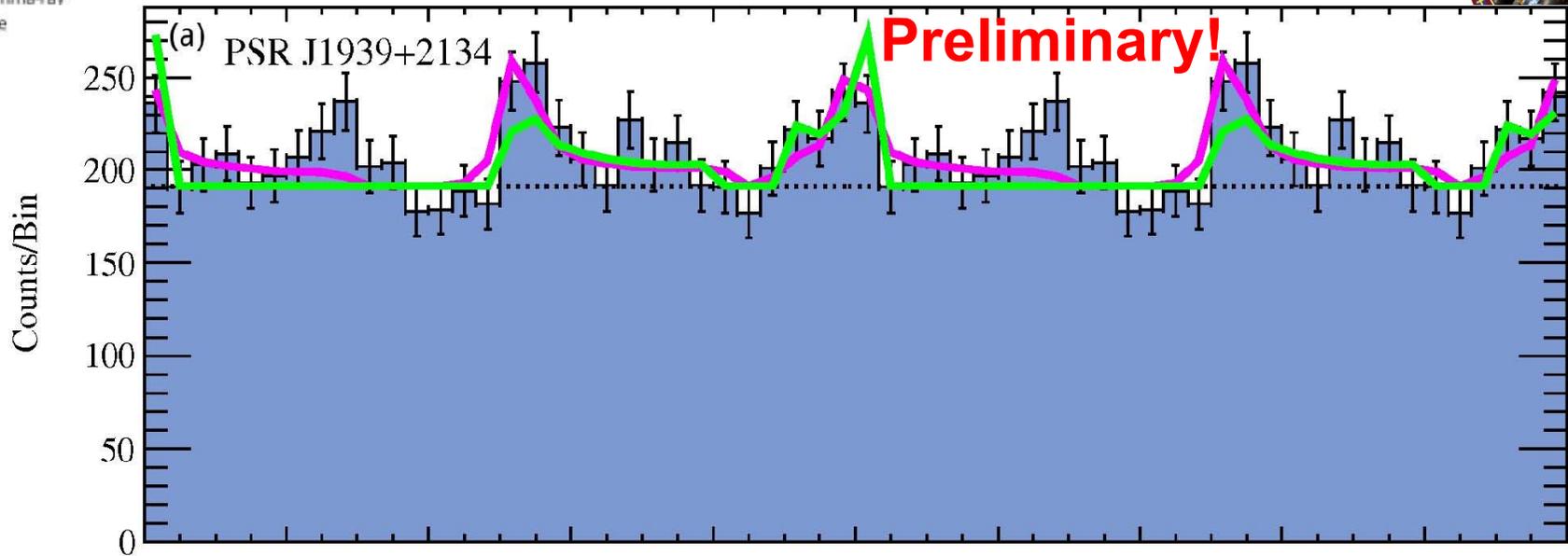
- **Implication 2:** Caustic radio and  $\gamma$ -ray LCs will be phase aligned

- Only true for Crab, some MSPs

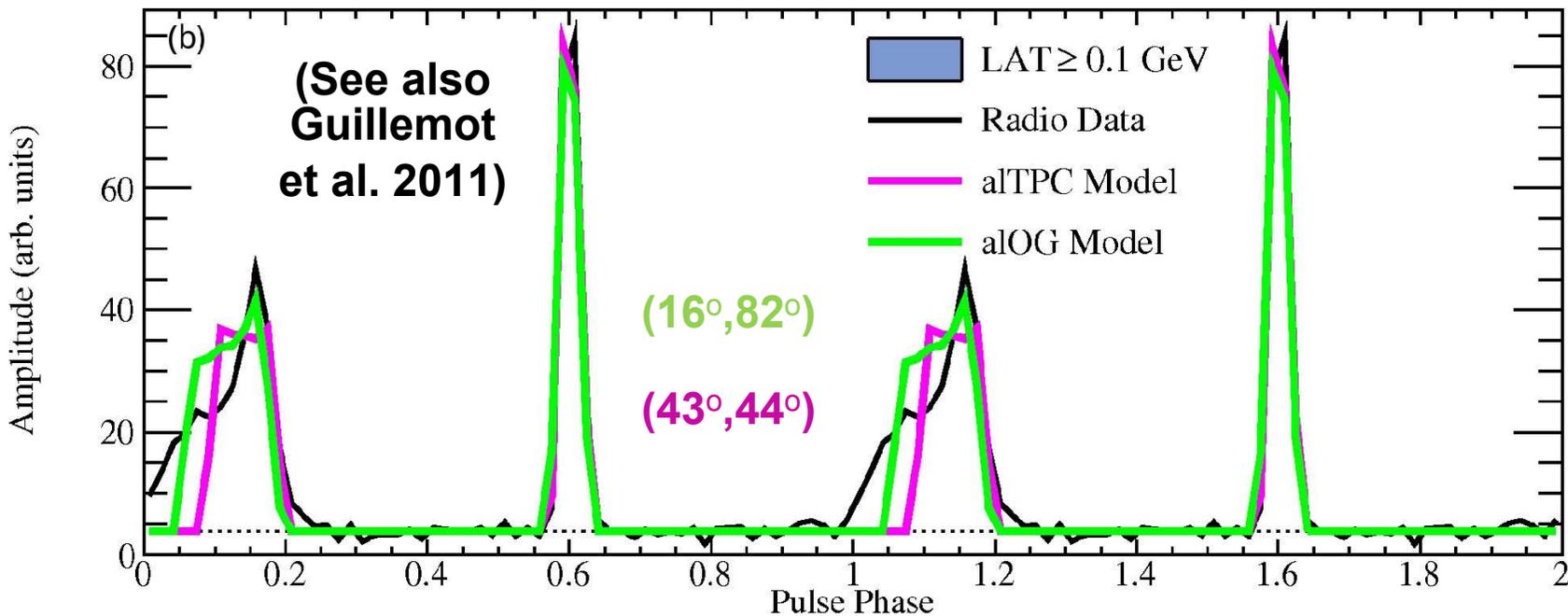
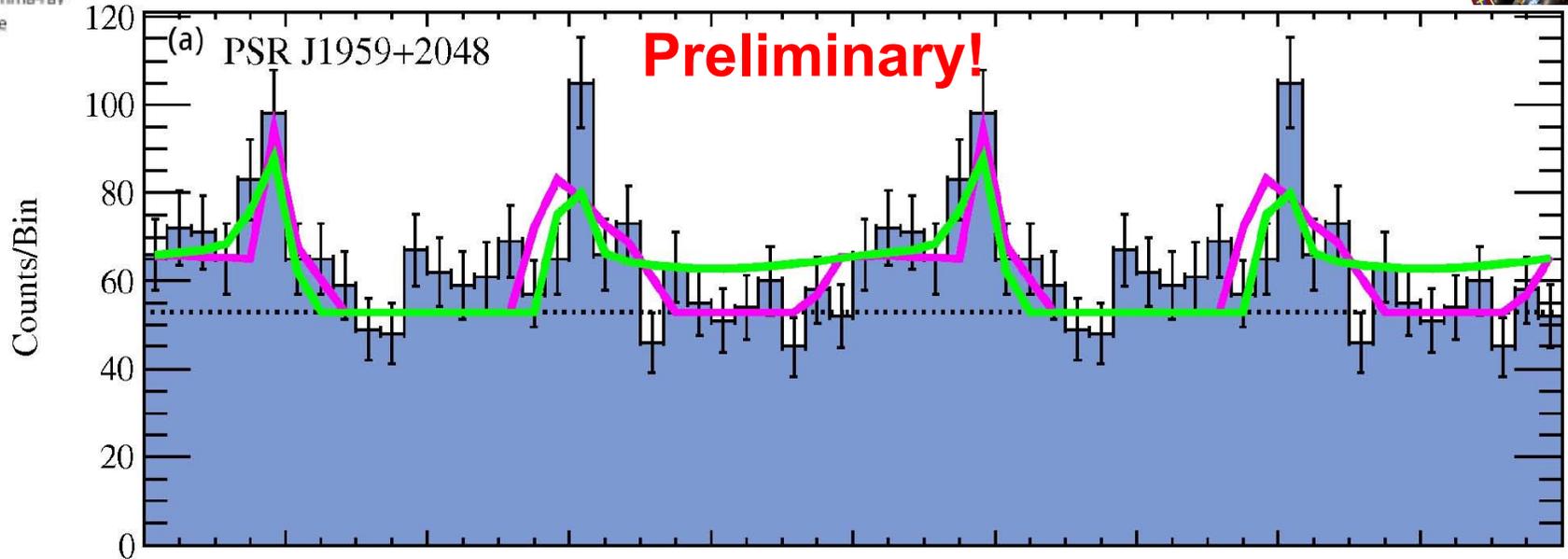
# Results: Altitude-limited Models



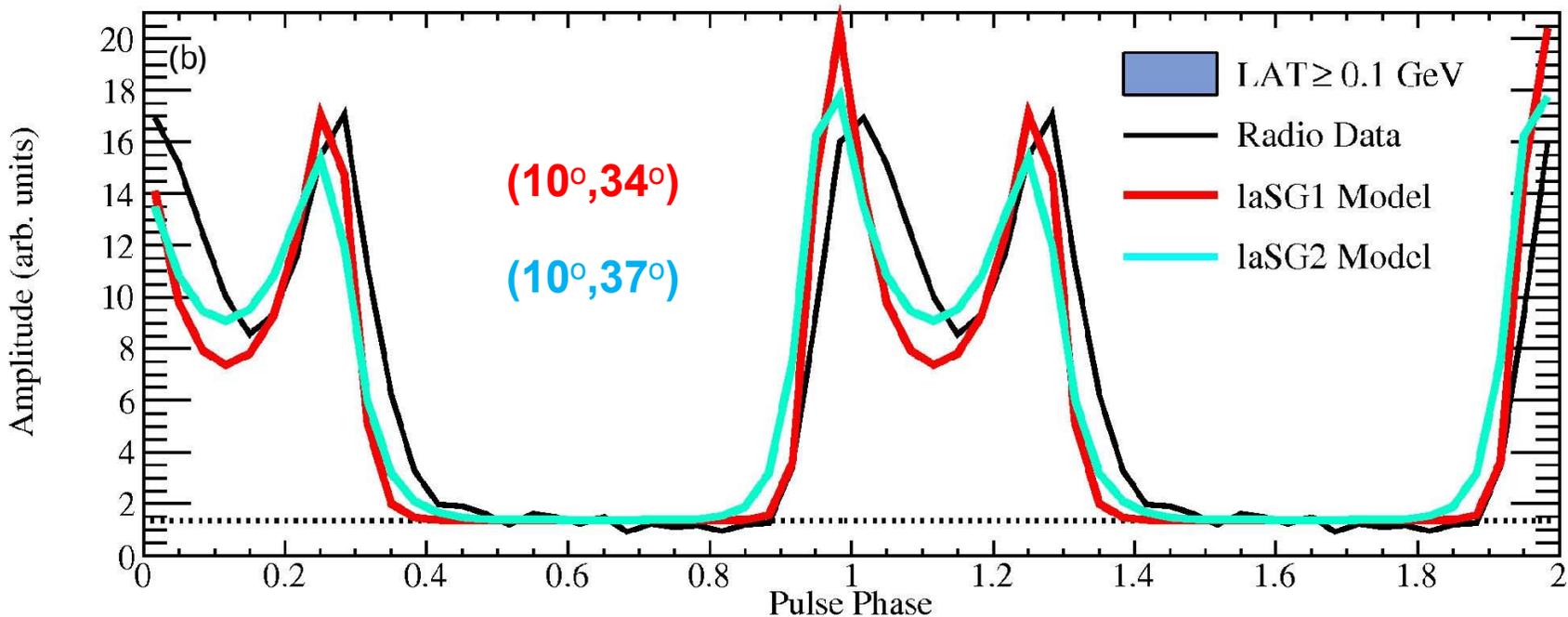
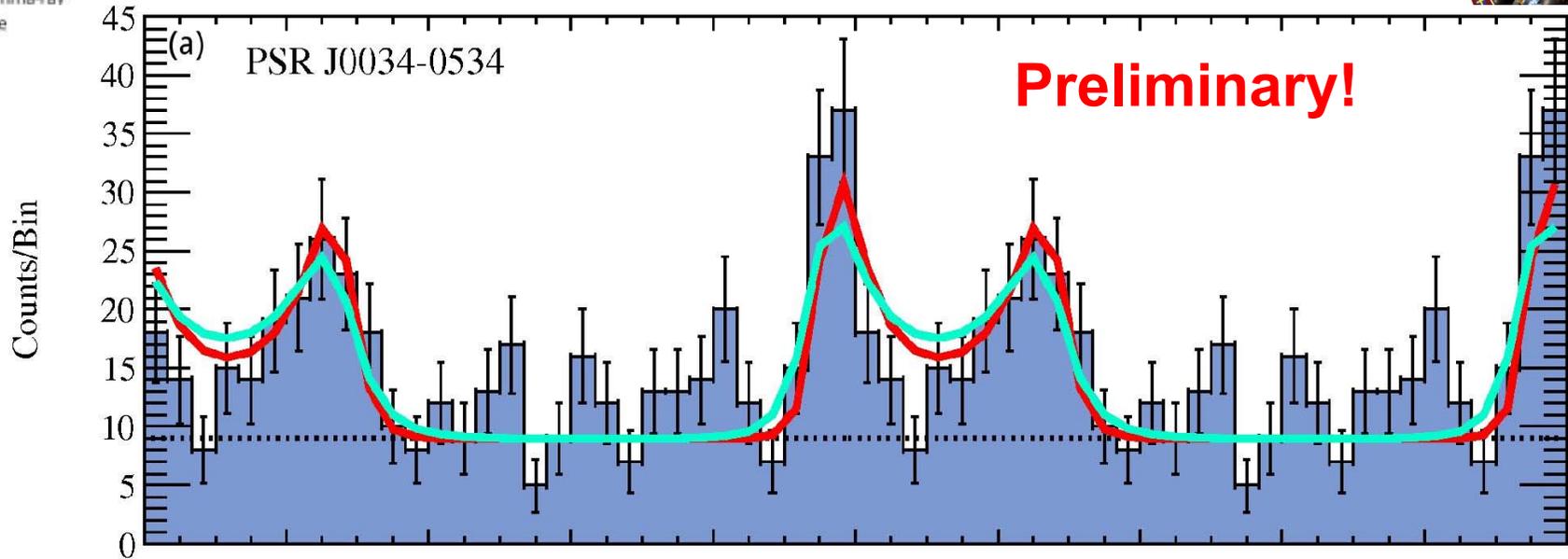
# Results: Altitude-limited Models



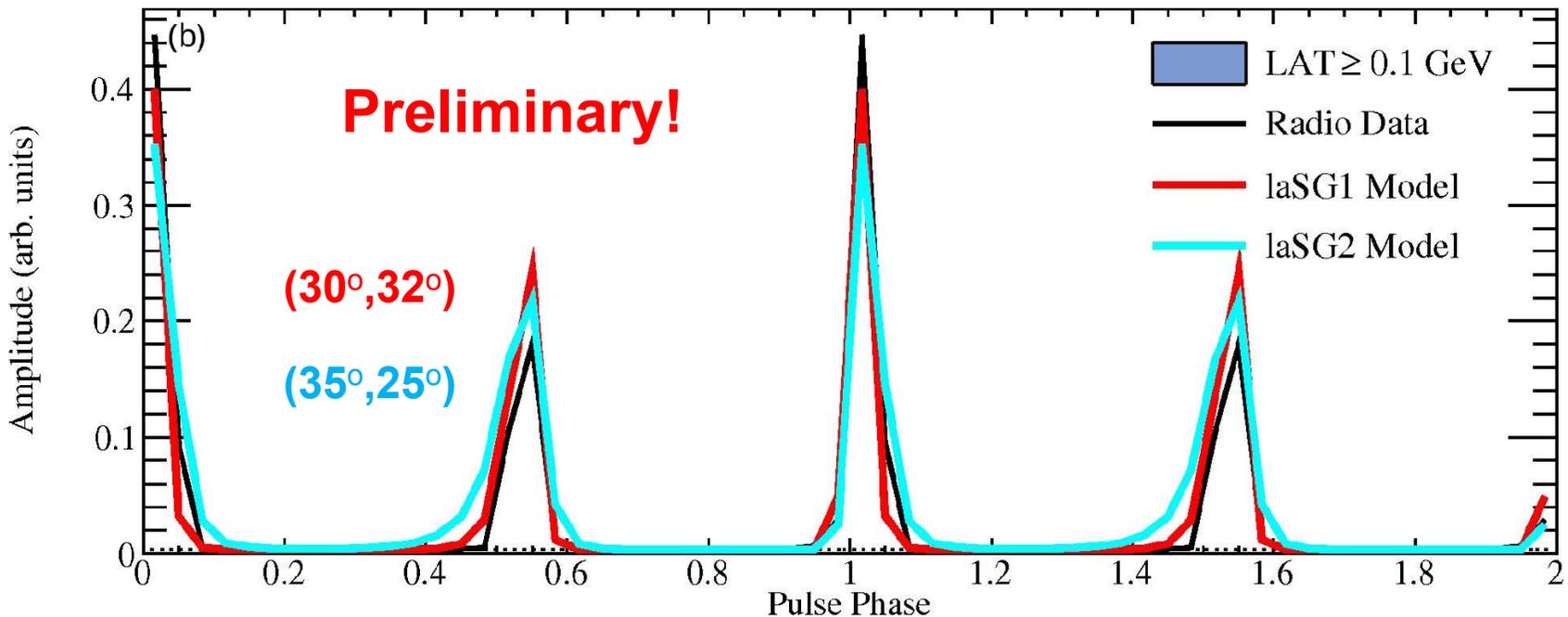
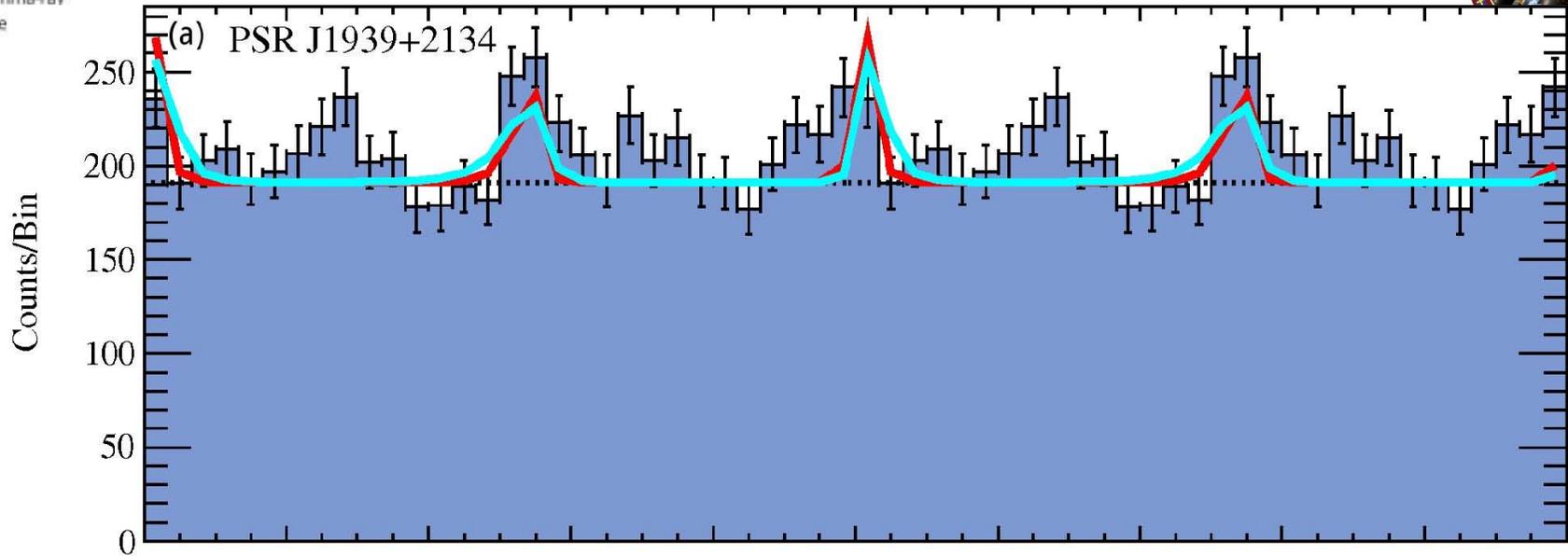
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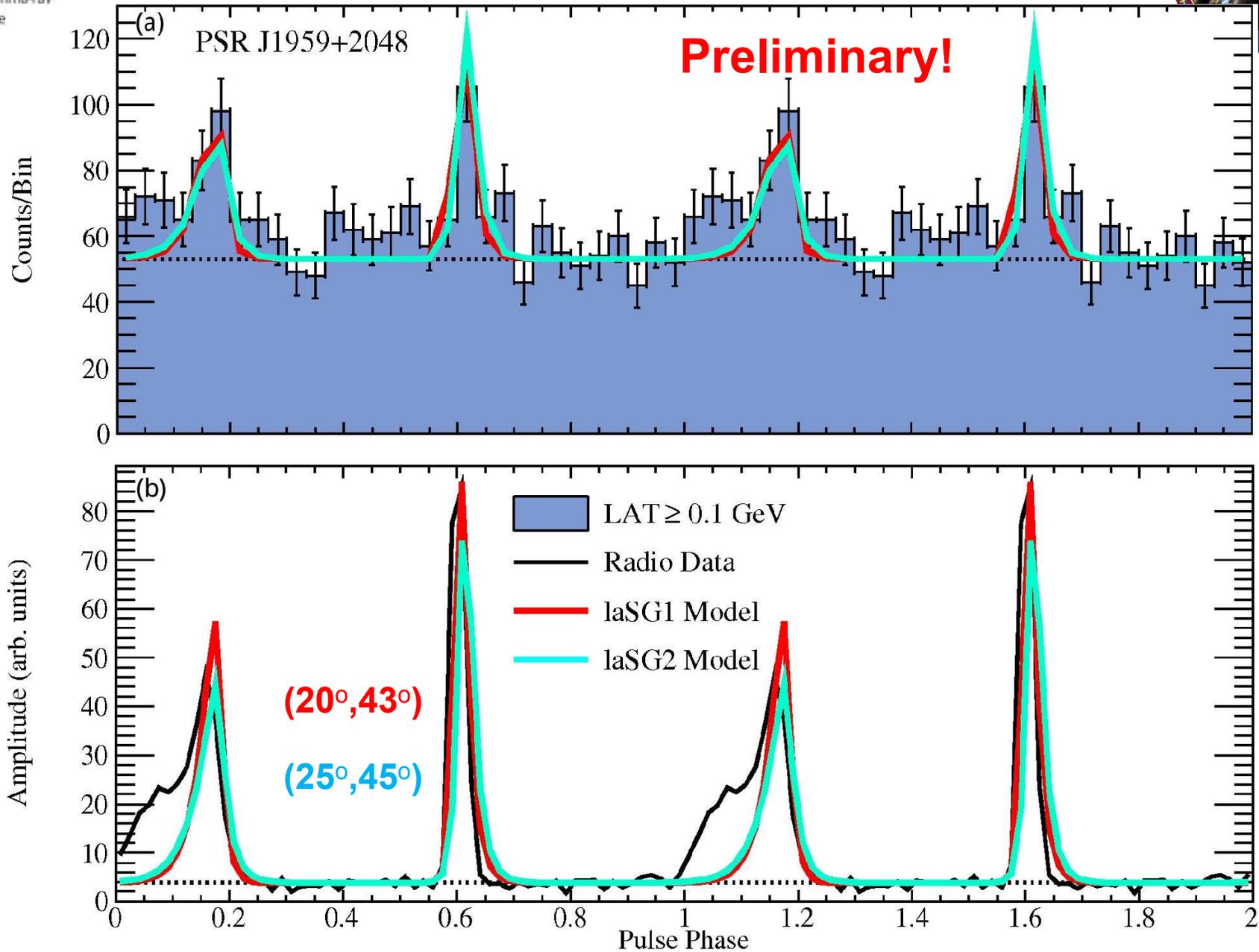
# Results: Low-Altitude SG Models



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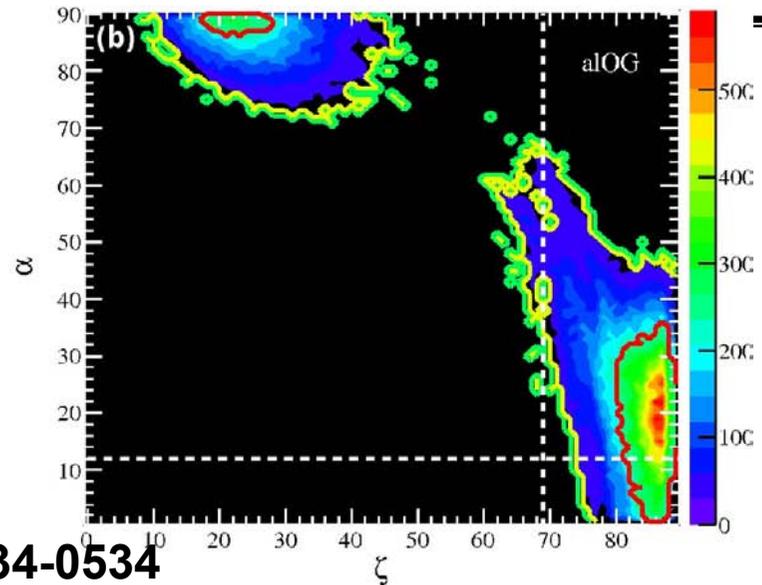
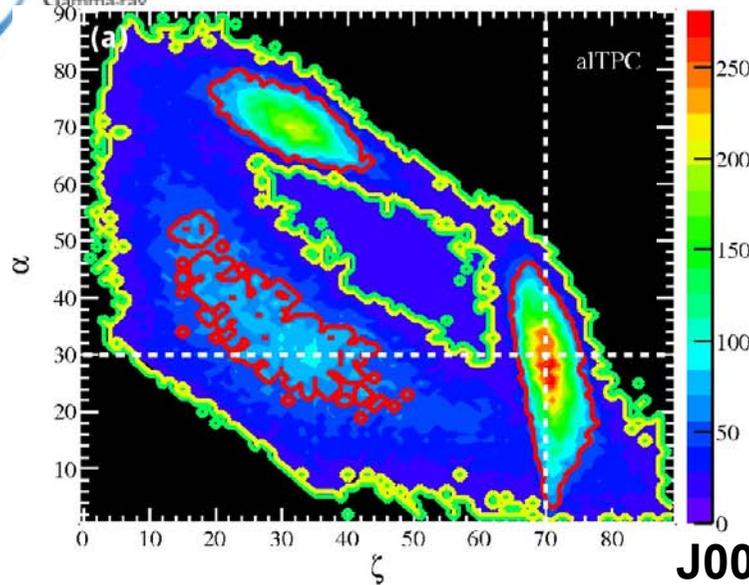


# Results: Low-Altitude SG Models





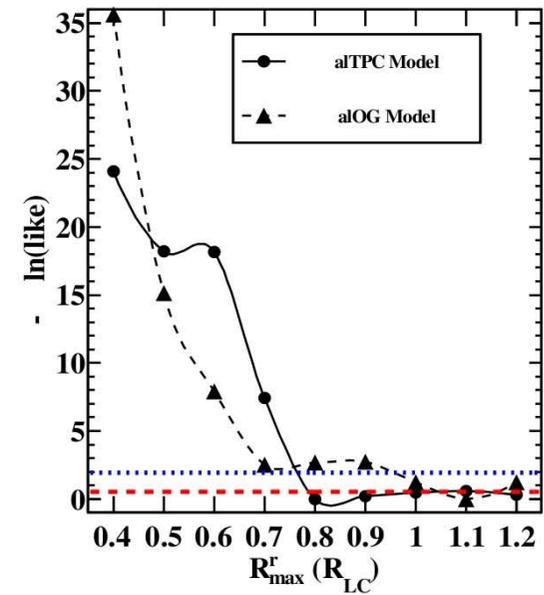
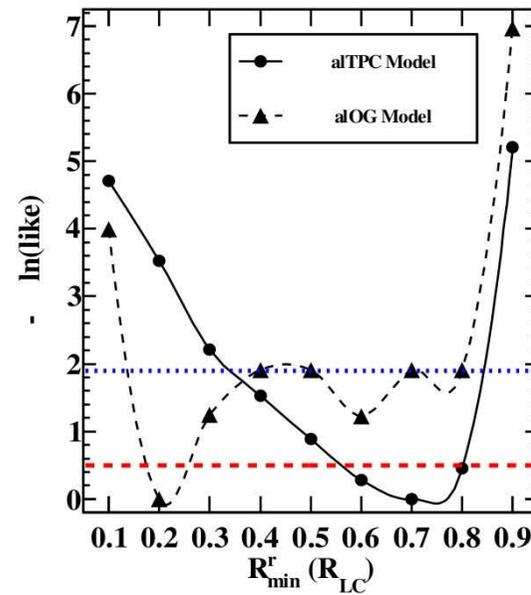
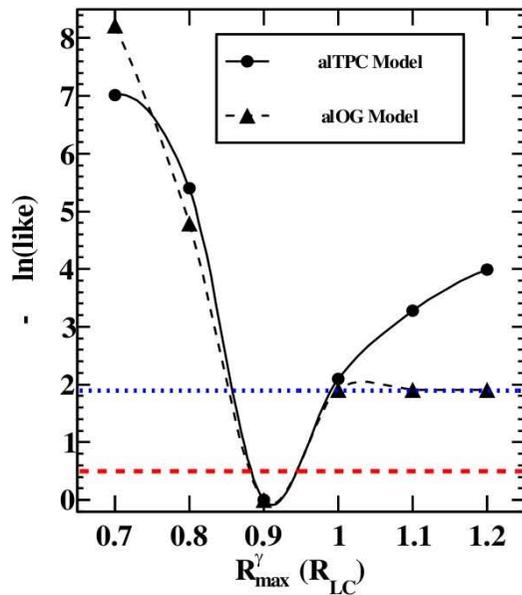
# Results: MCMC Contours



Constraints on geometry, gap widths, locations

~10% errors on radio altitudes

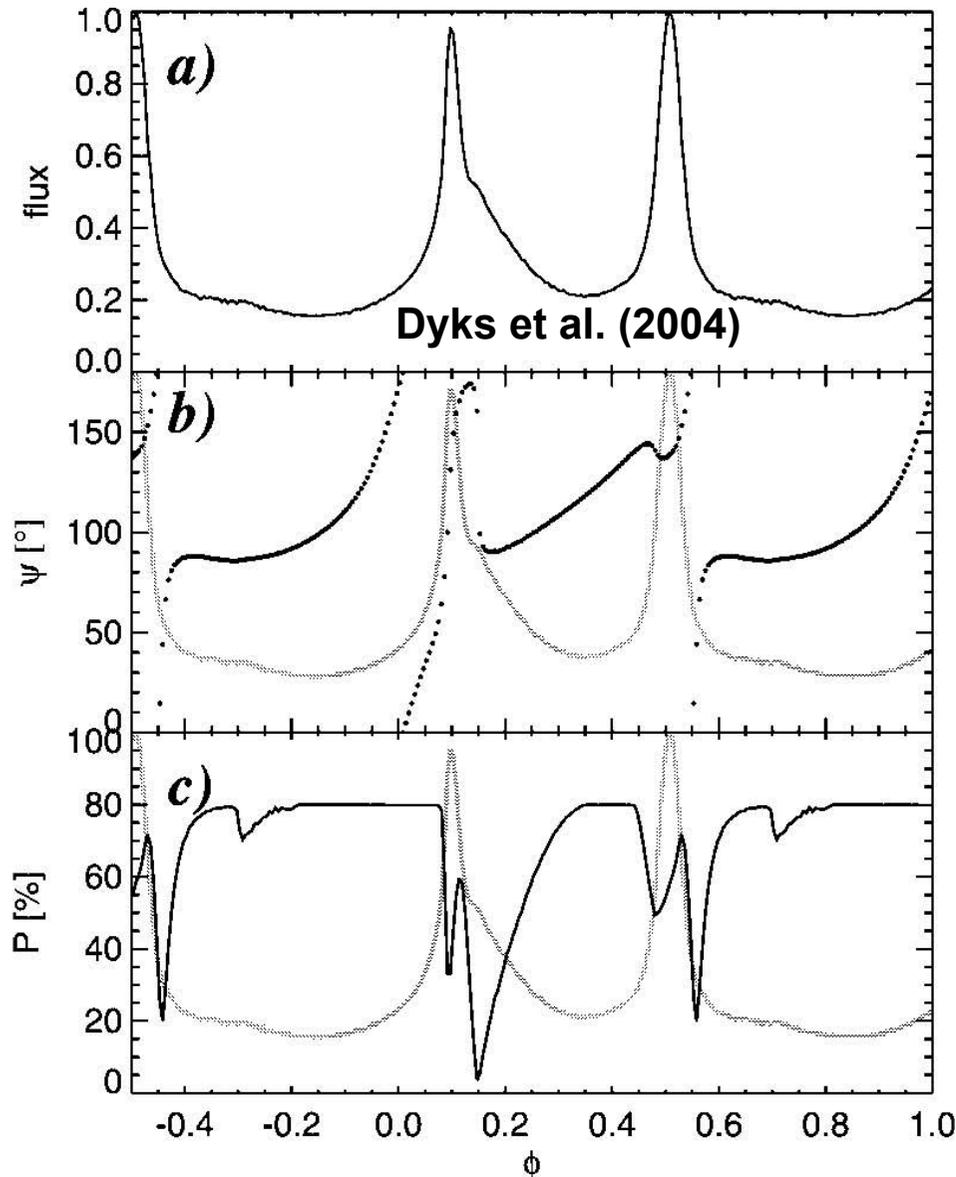
J0034-0534



Venter et al. (2011); Johnson et al. (2011); see poster by Johnson et al.



## Caustic Radio Emission



- RVM not really valid for MSPs

- Rapid PA swings

- “Mixing”: accumulation of radiation from different positions in magnetosphere - depolarization

- Potential discriminator for caustic vs. non-caustic emission

- Polarization properties of J0034-0534 (0% linear, small circular), J1939+2134 (rapid PA changes / mode switching), & J1959+2048 (0% linear, 4% circular) fit with the caustic hypothesis.

# Conclusions



- **Pulse shape & lags: LCs fit by different classes of models**
  1. **Standard OG / TPC:** radio proceeds  $\gamma$ -ray LC
  2. **PSPC:** radio has small lag w.r.t.  $\gamma$ -ray profile
  - 3a. **Altitude-limited OG / TPC:** Phase-aligned LCs; Co-located, extended, high-altitude emission
  - 3b. **Low-altitude SG:** Phase-aligned LCs; Co-located, near PCs.
- **aLOG / TPC preferred over laSG: wide, extended, caustic radio beams**
- **More free parameters: more pulse shapes available; limits on extent of emission regions**
- **Polarization measurements may be a possible discriminator for caustic emission**

## Future

- **Radiation models: spectra; pair creation in MSP magnetospheres**
- **MSP population studies**



# THANKS!

*“My hands have made both heaven and earth; they and everything in them are mine. I, the LORD, have spoken! I will bless those who have humble and contrite hearts, who tremble at My word” (Is. 66:2 NLT).*